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Geology of the Breitenbush River Area, Linn and Marion Counties, Oregon

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Structural Geology

The area is cut by a major N. 22° E.-trending fault that is here referred to as the "Hoover fault" for its exposure on the east end of Hoover Ridge. The Hoover fault separates northwest-tilted rocks of unit Tbl on Hoover Ridge from younger rocks east of the fault. The youngest rock cut by the fault is unit Tbu, where it is interbedded with unit Ts. No ages are available for the lower part of unit Tbu. Interbedded lavas of unit Ts have a minimum age of 19.4 million years (Ma) (White, 1980a,b; Fiebelkorn and others. 1982). The total down-to-the-southeast offset across the Hoover fault is unknown, but unit Tbg is about 300 m higher in elevation on the northwest side of the fault than on the southeast side between Beard Saddle (outside of the map boundary) and Tom Creek. Unit Tbg apparently dips toward the southeast at Tom Creek, so the net slip is probably smaller than the difference in elevation. The Tom Creek area is the only place where the same unit has been found on both sides of the Hoover fault. The fault mapped at Tom Creek is very close to the edge of the map, so more faulting could be present west of the map boundary. It may be that the fault has lesser net slip in the Tom Creek area than in areas to the north. It is also possible that there is an angular unconformity between units Tbq and Tbl. Dips in unit Tbl near Stahlman Point (west of the map boundary near Beard Saddle) are toward the northwest, whereas overlying rocks of units Ts and Tbq appear to have subhorizontal dips. This discordance in dips suggests that a period of deformation and erosion preceded unit Tbq. Therefore, some deformation could have occurred on the Hoover fault prior to unit Tbq time that would not be detectable as offsets of unit Tbq. Additional mapping in the Stahlman Point-Beard Saddle area is critical to resolution of this problem.

Rocks on the east block of the Hoover fault have mostly subhorizontal or gentle southeasterly to southwesterly dips, unless they have been deformed adjacent to the Hoover fault. Numerous small faults tilt the east-block rocks on the western margin of Boulder Ridge. The largest block is tilted toward the northwest in the Cliffs Creek area. This local fault block is separated on its southeast side from the rest of the east-block rocks by a northeast-trending subsidiary fault that is exposed on the ridge separating Cliffs and Cultus Creeks. The exposed fault plane strikes N. 35° E., dips 63° to the southeast, and has slickensides raking 23° to the southwest. Unit Tbq is locally offset a maximum of about 240 m down toward the northwest across the fault. If the exposed slickensides and dip are representative of the direction of net slip and the attitude on the entire fault zone, then the fault is a high-angle reverse fault with left-lateral oblique slip. However, the irregular trace of the fault across the topography offers no support for the easterly dip or for a large component of strike-slip movement. If the irregular trace of the fault reflects a local irregularity in the fault plane, then this may not be relevant to the fault as a whole. The northwest-tilted sequence is separated from gently dipping east-block rocks to the northwest by an inferred fault that roughly follows the Breitenbush River. Stratigraphic offset across this inferred fault is difficult to estimate but is probably small, with the northwest side down. The northwest-tilted block thus appears to be a northeast-trending monoclinal flexure that has been broken at the flexure points. The net result is that the rocks northwest of the flexure are displaced downward relative to rocks southeast of the flexure. The flexure could be the result of secondary folding caused by a small component of left-lateral shear on the Hoover fault.

Although there is no evidence of large-scale compressional folding, the northwesterly dip of the rocks on the northwest side of the Hoover fault at Hoover Ridge and the southwest to southeast dip of rocks on the southeast side of the fault on Boulder Ridge can be interpreted to form a faulted anticlinal structure (see descriptions of the Breitenbush anticline by Thayer, 1939). The fact that the fold axis is coincident with faults introduces other possible interpretations. The southwestward dip of unit Tbq along Boulder Creek could be the southwestward-plunging nose of this anticline. However, if, as suggested above, units Tbq and Tbl are separated by an angular unconformity, then dips on the east block measured in unit Tbq and younger units may have little or no relationship to dips of unit Tbl on the west block of the Hoover fault. Even dips measured in rocks mapped as unit Tbl on the southeast block are not necessarily helpful, because it is not known with certainty whether unit Tbl on the southeast block is correlative to or even approximately contemporaneous with unit Tbl on the northwest block of the Hoover fault. It is possible that some northwestward-dipping rocks of unit Tbl lie beneath the southeast-block rocks mapped as unit Tbl and are separated from them by an angular unconformity. The "anticline" would, in that case, be an artifact of the faulting. The relatively high dip of the older rocks on the northwest block relative to the younger rocks of the east block and the abrupt change of dip across the Hoover fault support this interpretation.

If a marker unit contemporaneous with unit Tbl could be correlated across the Hoover fault, this would lend credence to the concept of an anticline. It would also help to establish the amount of offset that may have occurred before deposition of unit Tbq. For example, if unit TIs, which is conformable on top of northwesterly dipping rocks of unit Tbl at the mouth of the Breitenbush River (west of the map boundary), could be located on the southeast block, this would suggest that the sequence was folded. Drilling to 2.5 km on the southeast block (Sunedco Well No. 58-28) has failed to intercept either the unit TIs sequence or any other pre-Tbq unit that can be correlated across the Hoover fault. The unit Tbl sequence intercepted in Sunedco Well No. 58-28 appears to have a greater quantity of ash-flow tuff than is typical of unit Tbl cropping out on the northwest block. A highly altered, quartz-rich tuff intercepted in the lower part of the well is also not known to crop out anywhere on the northwest block. It is possible either that, owing to accidents of original rock distribution, no distinctive units correlate across the fault, or that dip-slip offset on the Hoover fault prior to the deposition of unit Tbq could be so large that the bottom of the 2.5-km-deep well is in units younger than any Tbl or Tls units that crop out on the northwest block of the fault. This amount of dip-slip would require an offset in excess of 4 km. This latter possibility could be tested either by deepening Sunedco Well No. 58-28 to see if unit Tis can be intercepted or by attempting to correlate the distinctive quartz-rich tuff from the lower part of the well to outcrops outside of the map area on the northwest block of the Hoover fault. If this extreme dip-slip offset is present, then the quartz-rich tuff should crop out somewhere above the unit TIs sequence on the northwest block.

Aside from some small-displacement, northwest-trending normal faults in the Outerson Mountain area (Clayton, 1976; Rollins, 1976); the only other major deformation in the map area is a northeast-trending fault, named the "Bruno fault," which crops out in a roadcut on the northeast flank of Mount Bruno. The Bruno fault strikes N. 30° E. and dips 80° to the southeast. The

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fault at the outcrop juxtaposes units Tmd and Tmb and is therefore younger than about 10 Ma. A flow of unit Tp dated at 6.1 Ma occurs on the southeast side of the Bruno fault on the southeast flank of Mount Bruno, but owing to the local lithologic similarity of units Tmb and Tp, it is not known for certain if the fault cuts unit Tp there. Unit Tp is apparently offset down to the east across the fault near Bruno Creek, although the palagonite-rich character of unit Tp on the east side of the fault versus the paucity of palagonite tuff in unit Tp west of the fault casts some doubt on the correlation. Down-to-the-east offset is also suggested by the increasing southeasterly dip of volcaniclastic interbeds in unit Tp as the postulated extension of the fault is approached from the east. These southeasterly dips could be caused by drag. If the palagonite-rich rocks on the east side of the projected fault are unit Tp, then there is dip-slip offset of about 370 m across the fault. The unit Tp sequence adjacent to the fault at Bruno Creek crops out at Bachelor Mountain, where the uppermost flow has a K-Ar age of 6.35 Ma. Unit Tub appears to thicken abruptly across the southwestward extension of the fault, suggesting that unit Tub is lapping onto an east-facing fault-line scarp. The base of unit Tub has K-Ar ages of 2.7 to 3.1 Ma, so the fault was active prior to about 3.1 Ma. The fault was therefore probably active sometime between 3.1 and 6.35 Ma.

The down-to-the-east offset and age of the Bruno fault are similar to ages and offsets inferred for faults bounding the west side of a regional graben in the High Cascades of central Oregon (Allen, 1966; Taylor, 1980). However, the N. 30° E. strike of the fault where it crops out does not match the nearly north-south trend of the postulated graben faulting. The fault is also west of the North Santiam River, not at the river, as inferred by Allen (1966). It is possible that the fault extends to the northeast through Woodpecker Ridge and the Sentinel Hills, where it is obscured by younger lavas. This extension cannot be proved with available stratigraphic information. The fault also apparently extends southward where it merges with a zone of down-to-the-east fault-ing with a more northerly trend (Black and others, 1987).

Mineralization

Samples from most of the intense alteration zones were analyzed for a broad spectrum of ore metals. Only one sample had a metal content above background levels. The sample came from a quartz-veined shear zone in a tuffaceous debris flow of unit Tbl at Hoover Ridge. The shear zone trends N. 55° W. and dips 82° to the northeast with horizontal slickensides. Drusy quartz with open boxworks containing abundant iron oxide was sampled. Two batches of quartz fragments were analyzed, both labeled NS-473. One sample has 57 parts per million (ppm) Cu, 1,394 ppm Pb, 10 ppm Zn, 1 ppm Mo, 3.6 ppm Ag, and <5 parts per billion (ppb) Au. The other sample has 175 ppm Cu, 2,722 ppm Pb, 40 ppm Zn, <1 ppm Mo, 8.6 ppm Ag, and 35 ppb Au. The analyses were performed by Chemex Labs Ltd., North Vancouver, B.C., utilizing quantitative and semiquantitative multielement induction coupled plasma (ICP) analysis, except for Au, which was determined by fire assay/atomic absorption (AA). The sample location is in a roadcut at sec. 29 Dbacc, T. 9 S., R. 6. E., long 122°5'53" W., lat 44°45'44" N.

Walker and others (1985) found anomalous contents of metallic elements in rocks and stream sediments from the Battle Creek area and in rocks from the ridge immediately east of Dunlap Lake. The former area had rock samples with maximum values of >20,000 ppm Cu, 150 ppm Pb, 500 ppm Zn, 7 ppm Mo, 200 ppm Ag, and 350 ppb Au. The latter area had rock samples with maximum values of 20 ppm Cu, 20 ppm Pb, <200 ppm Zn, 20 ppm Mo, 15 ppm Ag, and 150 ppb Au. The analyses were obtained by semiguantitative spectrographic analysis. Walker and others (1985) concluded that these areas have moderate mineral potential.

Geothermal Resources

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Thermal fluid has been encountered at two localities in the map area. Thermal fluid reaches the surface at Breitenbush Hot Springs, and a thermal aquifer was encountered in Sunedco Well No. 58-28 at a depth of 752 to 782 m. The hot springs have a temperature of about 86 °C (Mariner, 1985), with temperatures in adjacent shallow wells as high as 110 °C at 100 m (Blackwell and

others, 1981). The thermal aquifer in Sunedco Well No. 58-28 had a temperature of 136 °C, when measured by a maximum-reading thermometer during drilling (A. Waibel, unpublished data, 1982). A thermistor log run about six months after drilling measured a maximum temperature of about 115 °C in the same part of the well (Blackwell and others, 1986). The second temperature reading was taken after the aquifer had been cemented off and cased. It is possible that injected cement and drilling fluid may have disturbed the natural flow of water in the aquifer enough to account for the discrepancy between the two temperature readings. The complete temperature-depth profile of Sunedco Well No. 58-28 is not available, but, from data in hand (A. Waibel, unpublished data, 1982; Blackwell and others, 1986), it is apparent that the thermal aquifer has raised the temperature gradient above regional background values (Priest, 1985). No stable temperature readings are available for the lower part of Sunedco Well No. 58-28, but the maximum recorded bottom-hole temperature of 141 °C (A. Waibel, unpublished data, 1982) is consistent with a minimum background gradient of about 56 °C/km (Priest, 1985). This gradient is consistent with gradients expected for sites in the Cascade heat-flow anomaly of Blackwell and others (1978, 1982) (Priest, 1985).

Thermal fluids in the area occur in unit Ts near its lower contact with unit **Tbq** or in unit **Tbq**. The hot springs emerge from fractures in unit Ts near the contact with underlying unit Tbq. The thermal aquifer in Sunedco Well No. 58-28 is located in fractured and sheared tuff of unit Tbq near the contact with overlying unit Ts (see cross section). Anomalously high temperature gradients occur near the hot springs and near Sunedco Well No. 58-28. The gradients decrease gradually toward the east and fall off abruptly to background values a short distance to the west of the well (Blackwell and others, 1986). This is consistent with an easterly dipping heat source, probably the aquifer intercepted in the well (A. Waibel, personal communication, 1985). The dip of the Breitenbush Tuff in the area adjacent to the well is approximately 10° to the east-southeast. The thermal fluid may thus be flowing upward along permeable zones in the tuff from sources under the High Cascades to the east. If the fluid cools by conduction and mixing with cooler fluids as it flows, then it may be significantly hotter to the east. Estimated reservoir temperatures for Breitenbush Hot Springs are 176 °C (sulfate-water method), 174 °C (anhydrite method), 166 °C (quartz method), and 148 °C (Na-K-Ca method) (Mariner, 1985). The higher estimated temperature are probably most representative of the actual reservoir temperature (Mariner, 1985). The proposed geothermal model could be tested by drilling and sampling a 2-km hole at sec. 36 Ddd, T. 9 S., R. 7. E.

Analytical Procedures

Approximately 165 whole-rock chemical analyses were utilized in the study to help define and characterize stratigraphic units and to search for economic minerals. These data will be presented in an open-file report to be published by the Oregon Department of Geology and Mineral Industries. The data were generated by atomic absorption spectrophotometry, Christine McBirney, analyst, University of Oregon, and by quantitative and semiquantitative multielement ICP analysis at Chemex Labs, Ltd. Multiple splits of samples and previously analyzed samples were submitted to aid in quality control.

K-Ar data were generated by Robert Duncan, Oregon State University, Corvallis, Oregon, and Paul Damon, University of Arizona, Tucson, Arizona, utilizing standard methods. ⁴⁰Ar/³⁹Ar data were generated by Daniel Lux, University of Maine, Orono, Maine, utilizing standard methods. In some cases, where the radiometric dates were obviously in error (e.g., an older date stratigraphically above a younger date), the samples were rerun. In most cases, the dates were exactly the same in the second run, suggesting that the errors were not in the analysis but were in the assumption that the isotopic systems had been closed to K and/or Ar exchange.

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Table 1. (See accompanying map.)

Table 2. 40 Ar/39 Ar data for samples from units Tp and Tmb in map area and from unit TIs in Hall Ridge area west of map area

Sample no.	Geologic unit	J	Plateau age (Ma ± 10)	Total fusion age (Ma)	Temp. ("C)	⁴⁰ Ar. ³⁹ Ar		³⁶ Ar ³⁹ Ar	Moles ³⁹ Ar	³⁹ Ar (%)	⁴⁰ Ar _{rad} (%)	K/Ca	Apparent age (Ma)	Location T.(S.)/R.(E.)/sec.	Latitude (N.)	Longitude (W.)
NS-462-W	Тр	0.006097	6.10±0.91	5.98	865 985	3.32	2.4084	0.0099	505.3 353.3	43.2 30.2	17.0 17.6	0.2031	6.21 ± 0.16 5.58 ± 0.26	11/7/4 Bdbd	44°39'00"	121°57'23″
					1065	3.23	10.7515	0.0119	173.1	14.8	16.7	0.0452	5.96 ± 0.66			
					1155	4.65	18.9252	0.0190	93.1	8.0	11.5	0.0255	5.97 ± 1.80			
					FUSE	11.84	34.1494	0.0473	44.6	<u>3.8</u>	5.1	0.0140	6.77 ± 2.67			
					Total				1169.4	100.0						
NS-328-W	Tmb	0.006077	6.45±0.46	8.56	825	2.62	8.3288	0.0091	238.9	46.6	21.8	0.0585	6.30 ± 0.65	10/7/35 Ddbd	44"39'23"	121*56*56*
					925	2.45	9.0770	0.0086	133.4	26.0	24.4	0.0536	6.60 ± 0.70			
					1000	3.41	14.9949	0.0124	26.4	5.2	27.1	0.0323	10.23 ± 3.40			
ł					1075	5.28	22.9189	0.0210	32.8	6.4	17.2	0.0210	10.07 ± 3.77			
					1145	9.57	28.8951	0.0376	38.4	7.5	8.1	0.0166	8.69 ± 5.20			
					FUSE	18.66	29.765 9	0.0636	42.7	<u>8.3</u>	12.0	0.0161	24.97 ± 1.78			
					Totał				51 2.6	100.0						
NP-826-P	Tis	0.005564		26.46	825	5.85	6.7180	0.0106	179.7	17.7	55.2	0.0726	32.28 ± 0.41	9/5/35 Cdac	44°44'34"	122''09''40''
					900	3.42	5.6900	0.0044	304.2	30.0	74.7	0.0857	25.57 ± 0.31			
					940	3.19	5.1220	0.0036	203.7	20.1	78.3	0.0953	25.01 ± 0.42			
					1000	3.17	4.9430	0.0040	120.0	11.8	74.5	0.0988	23.68 ± 0.40			
					1025	3.83	5.3640	0.0058	59.7	5.9	65.8	0.0910	25.23 ± 1.37			
					1050	5.14	4.2900	0.0100	83.4	8.2	48.7	0.1139	25.03 ± 0.99			
					FUSE	4.70	12.8200	0.0101	63.0	6.2	57.6	0.0379	27.25 ± 0.99			
					Total				1013.7	100.0						

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GEOLOGIC MAP OF THE BREITENBUSH RIVER AREA, LINN AND MARION COUNTIES, OREGON TIME ROCK CHART **DESCRIPTION OF REGIONAL TIME-ROCK UNIT** ntroductio The volcanic rocks in the area have been informally subdivided into four regional time-rock units. This was done in order to allow the units to be conveniently correlated to regional units utilized on other geologic maps of the Cascade Range 0.292 + 0.017 NS-212 Upper Pliocene and Quaternary volcanic and volcaniclastic rocks 0.46 0.21 This time-rock unit consists of rocks of various compositions that crop out in benches or plateaus that Whole rock 0.59 + 0.14 re intracanyon fillings in present stream valleys or in stream valleys that closely parallel present valleys 0.681 + 0.034 NS-217 Whole rock Subophitic to ophitic textures are common in basalts of the sequence; some are diktytaxitic. The base of NS-446 the sequence is not dated but is estimated to be between about 3.7 and 4.2 Ma (see discussions of units QTa 2.87 ± 0.18 MS-258 Whole rock and Tc, respectively). The top of the sequence includes the post-glacial block-and-ash flow of Mount Jefferson 3.06 ± 0.05 NS-225 (unit Qj). The rocks are equivalent to the volcanic rocks of the late High Cascades episode of Priest and 4.18 ± 0.07 NS-149 Whole rock others (1982, 1983) and to the upper part of the volcanic rocks of the High Cascade Range and Boring Lava PH-1D of Peck and others (1964). 4.67 + 0.07 4.74 ± 0.19 CT-68 Upper Miocene and lower Pliocene volcanic and volcaniclastic rocks 4.77 + 0.08 NS-151 This time-rock unit consists of baseltic lavas (units Tp and Tc) with minor amounts of tuff (unit, Tt) and 4.99 + 0.18 NS-733 Tmb Plag. rhyodacite (unit Td), which unconformably overlie the middle and upper Mionene rocks (units Tmb, Tma, 5.34 0.53 Devil-440 5.75 + 0.10 MS-239 Tmd, Tmt, and Tms). The relief on the erosional surface of unconformity increases from about 150 m to 6.0 • 0.9 DC-14 more than 370 m from the oldest (units **Tp**, **Tt**, and **Td**) to the youngest (unit **T**c) part of the section. Unlike the upper Pliocene and Quaternary volcanic rocks, which form obvious flat-topped successing present stream DC-114 valleys, these lavas crop out on the highest peaks of the Western Cascades. This geomorphic characteristic 6.35 0.15 NS-308 Plag. and the isotopic ages of these volcanic and volcaniclastic rocks were used to suparate them from the upper 6.42 · 0.33 NS-449 Pliocene to Quaternary section. Compositionally, the rocks of this sequence are identical to many of the DC-4 younger and older volcanic rocks. The most mafic lavas of the sequence are less silicic than the most mafic PH-40A Plag. rocks in underlying sequences, but the bulk of the sequence is identical in composition to the middle and upper Miocene sequence. The middle and upper Miocene rocks are, however, slightly more altered, with common alteration of olivine and, less commonly, orthopyroxene to green phyllosilicates. The upper Miocene and lower Pliocene lavas generally have a fresher, lighter color than the older lavas, weather to a light-tan color, and have more basalt with medium-grained ophitic and subophitic texture. The age of the base of 12.3 0.8 No.4 the sequence is unknown but is older than about 6.35 Ma and younger than about 10 Ma (see discussion FRL-4825 of unit Tp and Tmb, respectively). The top of the sequence is about 4.2 Ma (see description of unit Tc). No. 4 This time-rock unit is equivalent to the volcanic rocks of the early High Cascade episode of Priest and 14.5 · 0.2 14.7 · 0.2 PEH-77-9 Tla Whole rock PEH-77-9 others (1982, 1983) and the lower part of the volcanic rocks of the High Cascade Range and Boring Lava FRL-4824 of Peck and others (1964). FRL-4824 MS-256 Middle and upper Miocene volcanic and volcaniclastic rocks This time-rock unit consists of basalt and basaltic andesite (unit Tmb), andesite (unit Tma), dacite and rhyodacite (unit Tmd), with interbedded volcaniclastic sediments (unit Tms) and ash-flow tuff (unit Tmt), all of which unconformably overlie the Breitenbush Tuff and associated lavas and are unconformably DMS-43 overlain by unit **Tp** and younger rocks. This sequence fills a paleotopographic surface with about 200 to 400 m of relief. The rocks generally show some alteration of glass and mafic silicates, especially olivine NS-826 and rarely orthopyroxene, to green or yellow-green phyllosilicates. The lavas are compact to vesicular but 23.2 - 0.8 FRL-4823 never diktytaxitic. Mafic units mostly lack the small glomeroporphyritic clusters of 0.1- to 0.5-mm-long PEH-77-8 olivine and plagioclase crystals that are common in younger mafic flows. Ophitic to subophitic textures are 24.9 · 0.3 Bx 99 also much less common in basaltic layas of this group than in younger basaltic rocks. Nearly all of the 25.5 · 0.8 CT-8 lavas are quartz normative with silica contents (analyses recalculated volatile-free) mostly in excess of 50 percent, whereas the most mafic end members of unit Tp and younger mafic assemblages lack normative From Sutter, 1978. quartz and reach silica contents below 50 percent. The age is not well constrained but is younger than about From Laursen and Hammond, 19 From Hammond and others, 198 18 Ma and older than about 6.35 Ma (see discussions of units Tbp and Tp, respectively). The sequence is 4. From White, 1980a,b. 5. From Priest and others, 1983 equivalent to the volcanic rocks of the late Western Cascade episode of Priest and others (1982, 1983); This sequence corresponds to many of the rocks in the region mapped as Sardine Formation by Peck and others (1964), although the rocks at the type section of the Sardine Formation are actually much older (see 5. Modified by Fiebelkorn and others, 1982. 7. Location recalculated based on White (1980b). Locations lis discussion of unit Tis). Peck and others (1964) mapped most of this sequence as their volcanic rocks of the High Cascade Range and Boring Lava. igocene and lower Miocene volcanic and volcaniclastic rocks This is a thick (4,600-m) sequence of predominantly tuff (unit Tb) interbedded with and wite (unit Tla) and tholeiitic (iron-rich) lavas (unit Ts), tholeiitic volcaniclastic rocks (unit Tss), and basalticandesite (unit Date may be affected by low-grade rock alteratio TIb). These rocks are unconformably overlain by the middle and upper Miocene sequence. The top is approximately 18 Ma in age (see discussion of unit Tbp). No ages for the base are available, but the base is older than 26.46 Ma (see discussions of units Tbl and Tls). The rocks are equivalent to velcanic rocks of the early Western Cascade episode of Priest and others (1982, 1983) and the Little Butte Volcanic Series and the second s of Peck and others (1964). 1 Time boundary from Palmer (1983); upper and lower time boundaries of rock units are schematic. EXPLANATION Lavas of Triangulation Peak (upper Miocene) — Basalt and basalic andesite lavas capping SURFICIAL UNITS the highest peaks on the eastern margin of the Western Cascades. In must places, unit Tp reaches Tmt Alluvium (upper Pleistocene and Holocene) — Fluvial sands and gravels with minor lacustrine higher elevations than units Tub, QTa, or Tc. The base of the section is everal hundred feet above Qal deposits the bases of units Tub, QTa, and Tc, except where downfaulted on the sast side of Mount Bruno and Bachelor Mountain. The lithology is essentially identical to that if units Tub and Tc, and parts of the section characterized by basaltic andesite and quartz-normalive basalt are identical to Colluvium (upper Pleistocene and Holocene) — Unconsolidated talus and deposits of mixed underlying units of unit Tmb. This makes it difficult to identify unit Tp in some areas, such as the soil and rock that have been transported significant distances by creep and slope wash east side of Bachelor Mountain, without isotopic ages. The basalt commonly has fresh or iddingsitized olivine phenocrysts and ophitic to subophitic clinopyroxene 🐞 a holocrystalline plagio-Landslide deposits (upper Pleistocene and Holocene) clase-rich groundmass and is rarely diktytaxitic. Basaltic andesites have abundant plagioclase clinopyroxene, and a minor number of olivine phenocrysts in a fine-grained to hypohyaline Ols groundmass. Unit Tp can be distinguished from unit Tmb in most places by its lack of alteration of mafic silicates or glass and by the presence of some lavas with glomemorphyritic clusters 2 to Slide block (upper Pleistocene and Holocene) Osh 4 mm in diameter of 0.1- to 0.5-mm-long olivine and plagioclase crystal a texture that is lacking in unit Tmb. Unit Tp locally contains abundant palagonite tuff (e.g., entern margin of Bachelor Mountain) and reaches a maximum thickness of about 320 m at Brune Creek. K-Ar ages range Slide block of unit QTb (upper Pleistocene and Holocene) from 0.27 to 9.5 Ma (Sutter, 1978; Fiebelkorn and others, 1982; Priest and Woller, 1982, 1983), but there are many conflicts between the ages and stratigraphic position. A fresh flow at the top of Outerson Mountain yielded an age of 6.30 ± 0.22 Ma. Because of the relatively high K (1.6 percent) and Slide block of unit Tmb (upper Pleistocene and Holocene) radiogenic "Ar (63 percent), this is probably the most accurate age from the lavas in the Outerson Mountain-Timber Butte area. The anomalously young ages of 0.27 Ma and 0.46 Ma on Timber Butte are probably the least accurate. These samples have extremely small amounts of radiogenic Slide block of unit Tmt (upper Pleistocene and Holocene) argon (see Table 1) and occupy about the same stratigraphic level as rocks dated at 6.30 Ma at Outerson Mountain. A K-Ar age of 6.35 ± 0.15 Ma was also obtained from a flow near the top of the section exposed at Bachelor Mountain. A "Ar-"Ar plateau age of 6.10 ± 0.91 Ma (see sample NS-462-Tbu W. Table 2 in text accompanying this map) was obtained on a possible downfaulted basalt of unit Slide block of unit Tbu (upper Pleistocene and Holocene) To on the southeast flank of Mount Bruno. Unit Tp was mapped primarily as the older basalt and basaltic andesite by Hammond and others (1980, 1982) Glacial-fluvial deposits (Pleistocene) — Includes till and outwash deposits Rhyolite (upper Miocene) - Banded vitrophyric rhyolite with 72-73 percent Si0, and 3.1-3.4 per-Qaf Td cent K₂0, reaching a maximum thickness of about 60 m near Crag Creak. The contact of unit Td with unit Tt has a relatively steep dip within the map area, suggesting either that unit Tt onlaps a plug dome of unit Td or that unit Td intrudes unit Tt. According to M. Conrey (written com-VOLCANIC UNITS Upper Pliocene and Quaternary volcanic and volcaniclastic rocks munication, 1986), a flow of unit Td is interbedded with unit Tt on the past margin of the map in Qj Block-and-ash flows of Mount Jefferson (upper Pleistocene and Holocene) ---- Pyroxene dathe Crag Creek area. Some block-size lithic fragments in block-and-ashflows within unit **Tt** near cite block-and-ash flows with numerous prismatic fractures on blocks, indicating emplacement the Tt-Td contact have a megascopic resemblance to unit Td. The bulk of the evidence suggests Tbp while hot. Unit **Gi** is about 30 m thick. Its occurrence in the Whitewater and Pamelia Creek valleys that unit **Td** is roughly contemporaneous with unit **Tt**, locally intruding lower parts of but also insuggests an origin from Mount Jefferson. The unit, which was locally eroded by late Pleistocene terbedded with unit Tt. Unit Td was mapped as undifferentiated Tertiary intrusions by Hammond glaciation, overlies some older moraines along the North Santiam River. Radiocarbon data indiand others (1980, 1982) cate that some parts of the deposit are older than 38,000 years (Beget, 1982). Hammond and others (1980, 1982) inferred that the deposit in the Pamelia Creek valley is younger than the last glacia-Tuff of Outerson Mountain (upper Miocene) - Nonwelded dacitic and andesitic ash-flow tuff tion. Unit Qj was mapped as the volcanic deposits of Mount Jefferson by Hammond and others locally interbedded with volcaniclastic sediments and andesitic or dacitic debris flows and block-Tt -(1980, 1982)and-ash flows. Dacite ash flows are cream colored with moderately abundant dark basaltic to an desitic lithic fragments and minor amounts of obsidian fragments. The andesite ash-flow tuff is Olivine basalt and basaltic andesite of Pigeon Prairie (upper Pliocene? and/or Pleisgray with abundant lithic fragments of dark-gray scoriaceous to compact basaltic andesite to andetocene?) — Very fresh appearing and locally diktytaxitic lava forming plateaus and intracanyon site and near Crag Creek is interbedded with rhyodacite lava and block-fich block-and-ash-flow deflows preserved as benches in the lower slopes of modern stream valleys. A small hill on Little Pi posits. All glass is hydrated. Pumice in the andesite ash flows is mostly altered to distinctive yelgeon Prairie with abundant float of cinders and a poorly exposed dike (unit QTv) may be the vent lowish clay materials resembling palagonite. Phenocrysts consist of a we percent of 1- to 2-mmarea for many of the intracanyon flows adjacent to it. The unit reaches a maximum thickness of long plagioclase crystals with minor amounts of clinopyroxene and, in me units, orthopyroxene. about 490 m at Little Pigeon Prairie. Unit QTb was mapped primarily as the younger basalt and Unit Tt reaches a maximum thickness of about 120 m at Crag Creek. The great thickness, abun basaltic andesite by Hammond and others (1980, 1982) dance of large lithic clasts in the tuff, and interbedded lava of unit Td at Crag Creek suggest that this was at or very near the vent area for these rocks. The rocks are overlain at Outerson Mountain Andesite and basaltic andesite (upper Pliocene and lower Pleistocene) — Unaltered flows of by a lava flow dated at 6.30 Ma (unit Tp). Unit Tt is younger than whit Tmb, the middle part of two-pyroxene andesite and pyroxene-rich basaltic andesite that form plateaus and benches on the which is dated at 10 to 11 Ma (see discussion below), and is lithologically similar to ash flows of the Deschutes Formation erupted between about 7.6 and 5 Ma (G.A. Smithand R.M. Conrey, personal communication, 1985). Unit Tt was mapped primarily as the Rhodode dron Formation by Hamsides of modern stream valleys. Maximum thickness of unit **QTa** is about 430 m on Woodpecker Ridge. A flow in the lower part of the section has a K-Ar age of 3.70 ± 0.10 million years (Ma (Sutter, 1978). A closely related andesite in the uppermost part of the sequence in the Sentinel Hills mond and others (1980, 1982) (east of the map boundary) has an isotopic age of 0.59 ± 0.14 Ma. Unit QTa was mapped primarily as the basalt of Minto Mountain or the younger basalt and basaltic andesite by Hammond and Middle and upper Miocene volcanic and volcanie matic rocks Hasalf and besettie and site (middle and upper Miorene) - Resettiendesite volumetrically more abundant than basalt. Unit **Tmb** contains a few thin two-pyrokene pleaste interbeds in the upper part near Outerson Mountain and Mount Bruno. The basalt generity has multiple generametrically others (1980, 1982) Hornblende-bearing nonwelded ash-flow tuff (lower Miocene) — Light-colored **i** Lava of Bingham Ridge (upper Pliocene and lower Pleistocene) — Olivine-augite basaltic Tbh andesite, olivine basaltic andesite, and augite andesit. Hypersthene is a common but minor tions of plagioclase and olivine phenocrysts varying to seriate texture, affough slightly phyric to phenocryst. Lava flows are fresh and compact with intergranular to intersertal textures. These highly phyric olivine basalt with intergranular or felty groundmasses so common. Include: rocks were erupted from vents in the High Cascades and flowed westward in canyons cut into presome locally thick sections of palagonite tuff and palagonite-rich laharic de sits in the Leone Lake and Outerson Mountain area. Unit **Tmb** reaches a maximum thickness dabout 550 m south of Pleistocene rocks. Total thickness is about 300 m north of the map area near Minto Mountain Unit **QTbb** includes normal and reversely polarized rocks. South of the map area, lava flows in the lower Triangulation Peak. Most K-Ar ages of these rocks have been affected to varying degrees by alter-5- 44°37'30 part of this unit interfinger with the upper part of the **Parkette** Creek sedimentary rocks dated at ation of mafic silicates or glass to green and greenish-yellow phyllosilicates and by weathering. An 121°52'30 about 1.8 Ma (Black and others, 1987). A lava flow from near the top of this unit at Grizzly Peak age of 11.5 ± 0.2 Ma obtained near the middle of the section at Devils Creek Sutter, 1978) is probably the least affected by alteration. Unit **Tmt**, which is interbedded in the middle of the section on (east of the map area) yielded a K=Ar are of 0.681 ± 0.034 Ma. Unit **OTbb** was mapped as the basalt ogy by George R. Priest, Neil M. Woller. of Minto Mountain by Hammond and others (1980, 1982) Boulder Ridge, was dated at 10.4 ± 1.2 Ma (Hammond and others, 1980, 1982). A slightly altered Mark L. Ferns, Oregon Department of sample of unit Tmb from the bottom of the section on the North Santiam River was dated by the Lavas of Battle Ax Mountain (upper Pliocene and lower Pleistocene) - Chiefly basaltic gy and Mineral Industries. "Ar/"Ar method in order to obtain a crystallization age. The attempt was not entirely successful. OTba andesite with lesser amounts of basalt and andesite and minor amount of hornblende-bearing da-Ages ranging from 6.3 Ma to 24.97 Ma were obtained during incremental heating with no obvious cite. Silica content is higher in the upper part of the section (White, 1980a). Unit QTba was Field mapping was completed primarily during the plateau (see Table 2 in text accompanying this map). Ages from the first two increments of heating erupted from the Battle Ax Mountain area west of the map boundary (White, 1980a) and reaches 1983 1984, and 1985 field seasons. The mapping was were 6.3 and 6.6 Ma, representing about 72.6 percent of the total "Ar released. These ages are simi a maximum thickness of about 490 m at Deadhorse Mountain. According to White (1980a), the lar to ages obtained on altered material in other parts of unit Tmb. Fairly consistent ages of about an entension of earlier mapping funded by USDOE youngest flows have reversed polarity, so unit **QTba** cannot be younger than about 0.73 Ma, the during the 1979 and 1981 field seasons and sum-10 Ma were obtained from the next two higher increments of heating, but these have high error esend of the Matuyama Reversed Epoch (Harland and others, 1982). K-Ar ages ranging from timates. The last increment yielded an age of 24.97 ± 1.78 Ma, which is clearly too old and may repmarined in Priest and Woller (1982, 1983). 1.26 ± 0.54 Ma to 1.95 ± 0.52 Ma were obtained on the rocks outside of the map area near Battle Ax resent excess mantle argon trapped in the cores of phenocrysts. If a whole-rock K-Ar age had been Mountain (Sutter, 1978; Fiebelkorn and others, 1982). Unit QTba was mapped primarily as the determined, it would have been about 8.56 Ma. The age of the base of the section is therefore not basalt of Battle Ax by Hammond and others (1980, 1982) known but is younger than about 18 Ma, the approximate age of the top of unit Tbp, and older than 11.5 Ma. Unit Tmb was mapped primarily as the basalt of Outerson Mountain by Hammond and Basalt and basaltic andesite of Mount Bruno (upper Pliocene) - Olivine basalt and others (1980, 1982). The section with andesitic interbeds near Outerson Mountain was mapped as Tub pyroxene-olivine basaltic andesite lava flows. Mostly unaltered compact lavas, although the lowest the Rhododendron Formation by Hammond and others (1980, 1982) two or three flows near Minto Mountain are diktytaxitic. Olivines are fresh to iddingsitized, and the groundmass is holocrystalline. The rocks also commonly contain glomeroporphyritic clusters 2 Andesite and dacite lavas (middle and upper Miocene) - Plagioclase-phyric, two-pyroxene to 4 mm in diameter containing 0.1- to 0.5-mm-long olivine and plagioclase crystals. Unit Tub Tma andesite with minor amounts of plagioclase-bearing two-pyroxene dacite vitrophyre. Unit Tma forms most of the western part of Minto Mountain and the southeast side of Mount Bruno. The thickens toward the Cub Point and Bachelor Mountain area, reaching a maximum thickness of lavas dip southeasterly at Mount Bruno, but the lower contact is at roughly the same elevation at about 370 m northeast of Cub Point. This thickening suggests that the Cub Point-Bachelor Moun-Minto Mountain as at the east end of Mount Bruno. Either the dip becomes subhorizontal between tain area was a major andesitic volcano that was adjacent to and contemporaneous with basalt vol Mount Bruno and Minto Mountain or the lower contact is roughly horizontal, but the lavas have an canic centers (unit Tmb) to the north. A sample west of Hawk Mountain yielded a K-Ar age of initial southeasterly dip. The unit filled and locally overtopped a deep paleo olcanic and volcaniclastic rocks of the lower part of the Breitenbush Tuff (Tbl) and in 11.8 ± 0.4 Ma (White, 1980a,b). A sample east of Dunlap Lake was dated at 11.2 ± 0.8 Ma (Sutter, approximately with the present location of the north-south-trending segment of the North Santiam Tbl 1978; Fiebelkorn and others, 1982). Unit Tma overlies unit Tmt with isotopic ages of 12.3 and 12.6 River. The bottom of this paleovalley is about 240 m above the present river valley. Unit **Tub** Ma south of Collawash Mountain and was mapped primarily as the basalt of Outerson Mountain by reaches a maximum thickness of about 490 m. K-Ar ages near the bottom of the section are Hammond and others (1980-1982) 3.06 ± 0.05 Ma (Minto Mountain) and 2.7 ± 0.1 Ma (southeast end of the ridge adjoining Mount Bruno). The uppermost lavas at Minto Mountain and Mount Bruno are not dated but must be older Dacite and rhyodacite lava (middle and upper Miocene) --- Banded, nearly aphyric vitthan 1.8 Ma, the age of unit **QTs** of Black and others (1987), which occupies a paleovallev cut in Tmd rophyric dacite and rhyodacite in thick flow units of limited areal extent, reaching a maximum unit **Tub** south of the map area. Unit **Tub** was mapped primarily as the basalt of Minto Mountain thickness of about 240 m at Grizzly Creek. These rocks occur at the same elevations as adjacent by Hammond and others (1980, 1982) basaltic andesite lavas of the lower part of unit Tmb in the Pamelia Creek-North Santiam area Upper Miocene and lower Pliocene volcanic and volcaniclastic rocks The rocks are in fault contact with units **Tma** and **Tmb** on the east and southeast sides of the main area of exposure; other contacts are buried. The lower part of unit Tmb could be lapping onto steep Lavas of Collawash Mountain (lower Pliocene) - Numerous thin flows of basalt and basaltic plug domes of unit **Tmd** or could be interbedded with them. In any case, the upper part of unit **Tmb** andesite that filled and overtopped a deep (370 m), north-northeast-trending paleocanyon starting overlies unit Tmd on the east flank of Mount Bruno. Unit Tmd is probably younger than the at Breitenbush Mountain and extending northward to the edge of the map. The rocks are mostly o youngest rocks in unit Tbu (18 Ma) and older or the same age as the middle of unit Tmb (10 to 11 very fresh appearance with little or no alteration. Basaltic andesites are compact and fine grained Ma). Unit Tmd was mapped primarily as the basalt of Outerson Mountain by Hammond and with olivine and plagioclase phenocrysts. Basalts are mostly olivine phyric with subophitic to inothers (1980, 1982) 5.00 tergranular groundmasses. The rocks in the upper part of the sequence also commonly contain glomeroporphyritic clusters 2 to 4 mm in diameter of 0.1- to 0.5-mm-long olivine and plagoclase Volcaniclastic sedimentary rocks (middle Miocene) - Light-colored tuffaceous mudstone and crystals. Unit Tc reaches a maximum thickness of about 600 m near Bald Butte, K-Ar ages southsiltstone with lithic-rich sandstone and a few carbonaceous beds. These rocks occur at and near the east of Collawash Mountain are 4.18 ± 0.07 Ma at the top of the section and 4.77 ± 0.08 Maat the base of unit Tmb. Sunedco Well No. 58-28 intercepted about 260 m of unit Tms, which contained bottom. K-Ar ages of 6.1 ± 0.31 Ma (White, 1980a) and 4.2 ± 0.3 Ma (Hammond and others, 1980) 2.000 five thin basalt flows and one thin welded tuff (A. Waibel and M. Gannett, written communication, were obtained from the middle of the section southeast of Collawash Mountain. A sample from

northwest of Hawk Mountain yielded a K-Ar age of 4.74 ± 0.19 Ma (White, 1980a). The bulk of the

age data thus favor an age of about 4.2 to 4.8 Ma, ages obtained southeast of Collawash Mountain

from the top and bottom of the section, respectively. Unit Tc was mapped primarily as older basalt

SEE ACCOMPANYING TEXT FOR THE LIST OF REFERENCES AND A DISCUSSION OF THE REGIONAL GEOLOGIC SETTING

and basaltic andesite by Hammond and others (1980, 1982)

1.000

1,000

2.000

3,000

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1985). Unit Tms is overlain by most of the unit Tmb section and is thus older than about 11.5 Ma (see discussion of unit Tmb). Unit Tms occupies a paleovalley cut in unit Tbp, which was erupted between about 18 and 19.4 Ma (see discussion of unit **Tbp**). Owing to poor exposure, the unit was not recognized by previous workers in the main area of outcrop near Skunk Creek

Table 1. K-Ar and fission-track data 10 7 5 Bcc 44 44 59 121 59 22" 0.128 10 8 16 Adaa #4 42'30" 121 49'40" 0.0871 11 71/2 1 Ccaa 44 38 36 121 51'18" 0.3262 11 7 9 Adca 44 38'08" 121 57'02" 0.690 14.3 121 56'45" 0.767 15.1 0.3830 10/7 3 Ccb 44 43 55 11714Baaa 0.772 40.6 0.416 121 55 15" 1.364 19.8 0.8767 9/7 25 Cabd. 44 45 35 121 53 55" 9/7 10 Daba 0.178 49.9 0.126 44 48 32" 121 55 50" 9 7 14 Bbb 121 55'49" 0.325 12.1 44 48 02 0.5184 9 7 33 Aba 44 45'20" 121 57 11" 1.4.6.7.12 8 7 21 Cac 44 51 57 121 57'31" Whole rock 0.78 42 0.639 0.663 121 55 08" 44 47 52" 0.724 37.4 0.6279 10 7 9 Dbcb 44 43 08" 121 56 47" 121 54 24 10 7 11 Aaa 44 43 24" 0.492 Whole rock 0.53 13 1.648 121 '56'42" 10 7 3 Ccc 44 43 42" 44°43'07" 121'55'46" Whole rock 0.49 9 0.514 10 7 10 Dac 9710Cda 121 56 25" Whole rock 0.44 29 C.458 44 48 10 10 7 4 Dold 44 43 47" 121 56'54" 122,90'33' 121 57'04' 0.963 61.5 1.062 11 6 12 Dadd 44 37 43" 44 39 32 10 7 33 Dccc 10 7 2 Add 9 6 36 Daa 44 44 09" 121 54 25" 1.089 44 44'55" 122'00'33" 0.444 6.5 44 49'05" 122 05 18" 9 6 4 Ccb 44 44 12" 121 55 11" 121 '58'22' 9710 Dat 44 48'27" 121 56'19" 44 41 03 121 59 05 10 7 19 Obb 97 10 Dab 44 48'27" 121 56'19" 10 7 19 Db 44 41 03" 121 59 05" 9 6 36 Bad 44 45'03" 122'01'11" 122 01 11" 9 6 36 Bad 44 45 03" 122'01'11" 9 6 36 Bad 44 45 03 122 01 11" 122 01 27" 122 01 27 44 44 18" 10 7 19 Acc 44 41 28" 121 59 46" 121 58 21" 121 59 49" 9 5 35 Cdac 44 44'34" 122'09'40" 0.736 9 6 24 Acb 44 46 53 122 01 01 3.12 44 46 53" 122 01 01" 9 6 25 Bca 8 7 29 Cbc 44 46'05" 122 01'29" 4. Whole rock 1.291 87.7 5.756 44 50'00" 121 59'01" section based on outcrop and road locations. 3. Whole-rock samples were dated at Oregon State University, Corvallis, Oregon, Robert Duncan, analyst: pla immediately east of Pametia Lake. Sample is from a unit not exposed in the map area. The sample is from the crest of the easternmost of the Sentinel Hills immediately west of lays Lake. Sample is from units that are closely related in age to adjacent Qta units that crop out in the V Sample is from outside the map area but from a unit that occurs in the map area

Ash-flow and air-fall tuff (middle and upper Miocene) — Lithic-rich welded to nonwelde ash flows interbedded with a minor amount of light-colored air-fall and lacustrine tuff. Unit which forms low to moderate slopes and is responsible for most of the large landslides in the reaches a maximum thickness of about 240 m in the southern part of map. A K-Ar age of 10.4 😹 Ma was obtained on uppermost units interbedded in unit **Tmb** on Boulder Ridge, and age 12.3 ± 0.2 Ma and 12.6 ± 0.2 Ma were obtained at the base of the unit south of Collawash Mount (Hammond and others, 1980, 1982; Fiebelkorn and others, 1982). The K-Ar ages of basal re south of Collawash Mountain are from an isolated outcrop that may not be representative of base of the unit elsewhere. Unit **Tmt** is everywhere younger than uppermost unit **Tbp**, was due at about 18 Ma, and was mapped primarily as the Rhododendron Formation or the Boulder **R** member of the Breitenbush Formation by Hammond and others (1980, 1982) Oligocene and lower Miocene volcanic and volcaniclastic rocks Breitenbush Tuff, undifferentiated (Oligocene and lower Miocene) - Dacite and and ash-flow, air-fall, and volcaniclastic tuff with a large component of mudflow and laharic deput containing abundant blocks and lapilli of mafic to silicic lavas and some welded tuff. Most of a rocks show some degree of alteration, primarily in the zeolite facies. The amount of rock affects b alteration increases with depth in the sequence. Alteration of uppermost rocks affects mainly g whereas lowermost rocks show pervasive alteration of plagioclase and, in some ca clinopyroxene. The rocks are locally veined by quartz, clay minerals, zeolite, and carbonate, 🙀 cating some hydrothermal metamorphism. Where possible, unit **Tp** has been subdivided in informal units listed below. Unit corresponds to the Breitenbush Tuff as mapped by Thayer (19 Volcanic and volcaniclastic rocks of the upper part of the Breitenbush Tuff (u Oligocene to lower Miocene) - Unit Tbu includes all clastic rock units in unit Tb from Tbg to the top of unit Tb. When possible, unit Tbu has been divided into quartz-bearin hornblende-bearing (Tbh), and welded pyroxene-bearing (Tbp) ash-flow tuff; elsewhere ferentiated unit Tbu contains interbedded nonwelded ash-flow tuff and volcaniclastic sand

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mudstone, and minor debris flows. Uppermost rocks have been dated at about 18 Ma (see de ription of unit **Tbp** below). An isotopic age of 22.0 ± 0.2 Ma, which was obtained on an altered ash flow near the Breitenbush River, may have been affected by the alteration. Basal flows are in terbedded with unit Ts and related rocks with isotopic ages of 19.4 to 25.5 Ma. Unit Tbu of ponds approximately to the Breitenbush Formation of Hammond and others (1980, 1982) Welded pyroxene-bearing ash-flow tuff (lower Miocene) - Includes all welded pyro bearing, hornblende-free ash-flow tuff above the quartz-bearing ash-flow sequence (unit Lithic-poor, clinopyroxene-bearing, welded ash-flow tuff with local epiclastic and air-fall tofin terbeds. Dense welding is much more common in this sequence than in older ash flows in Tbp contains several ash flows in simple cooling units that each exceed 50 m in thickness one partial cooling break was noted in a 120-m-thick, densely welded sequence at Bard Ridge. The rocks are reddish to dark gray and form prominent cliffs in many areas. Euteriti texture is locally prominent with some quite large (10- to 20-cm long) flattened pumice. Hit is more often obscured in densely welded zones. Contains 5 to 10 percent plagioclase (1- to 3 mm long crystals) with minor clinopyroxene \pm orthopyroxene in the matrix. Only minor (1 to $\frac{2}{3}$ percent) phenocrysts occur in the pumice. Unit Tbp contains only 2 to 5 percent andesitic and dacitic (?) lithic fragments (0.5 to 2.0 cm in length). Alteration varies from heavy zeolitization the obscures all texture (e.g., Coopers Ridge) to mild hydration of glass with fresh phenocrystate.g. uppermost units on the lower west slope of Mount Bruno). Unit Tbp reaches a thickness of a least 300 m on the western slopes of Mount Bruno. An ash flow in the upper part of the sequence on the North Santiam River yielded K-Ar ages of plagioclase of 12.3 ± 0.8 Ma and 12.7 ± 0.9 M (Laursen and Hammond, 1978). A fission-track age of the same ash flow was 18 Ma (Han and others, 1980, 1982). An andesite flow interbedded in the upper part of the sequence a der Ridge yielded K-Ar ages ranging from 14.5 to 17.7 Ma (Sutter, 1978; Fiebelkorn and d 1982; Hammond and others, 1980, 1982). Unit Tbp overlies unit Ts, which has K-Ar ages ing from 19.4 ± 0.4 Ma to 25.5 ± 0.8 Ma (White, 1980a). Assuming that the fission-track we the most accurate age on the upper part of the sequence, the age of unit **Tbp** is probably between about 18 and 19.4 Ma. Unit Tbp was mapped by Hammond and others (1980, 198 primarily as their Boulder Ridge and Blowout Creek members of the Breitenbush Formatic but also locally as their Cleator Bend member and beds of Detroit

welded ash flows characterized by sparse (0.5 percent), small (0.7-mm-long) hornblende, spars clinopyroxene, and very sparse quartz in the matrix. Lithic fragments are 0.5- to 3-cm-lor dark-gray phyric lavas comprising about 2 to 3 percent of the rock. Pumice is about 0.5 to 5 cr in diameter and comprises about 25 to 30 percent of the rock. The remainder is ash. Glass is en tirely altered to light-greenish phyllosilicates. The unit is locally as much as 180 m thick on the west end of Coopers Ridge. Unit Tbh overlies parts of units Ts and Tla and appears to underlie some Tla and Tbp units at Coopers Ridge. The age is thus between about 18 and 19.4 Ma. Unit Tbh was mapped primarily by Hammond and others (1980, 1982) as their Cleator Bend member of the Breitenbush Formation Quartz-bearing ash-flow tuff (upper Oligocene) — Nonwelded to partially welded altered silicic ash-flow tuff with interbedded epiclastic and are fail tuff units. Unit Tiq is characterized by about 0.5 percent heavily embayed 1- to 2-mm-long quartz crystals in the matrix. Unput lished lithologic logs by A. Waibel and M. Gannett from Sunedco Well No. 58-28 indicate the

some nonquartz-bearing ash flows may be locally interbedded with the unit. The rocks also con tain 5 to 6 percent 1- to 3-mm-long plagioclase crystals and 5 to 10 percent distinctive 0.5- to 4 cm-long aphanitic reddish-purple lithic fragments. Some ash flows contain 2 to 10 percent 0.5% to 5-cm-long dark-gray silicified lithic fragments of lavas or tuffs(?) and fragments of cryptocrystalline or microcrystalline silica. Pumice fragments that are 0.5 to 15 cm long comprise about 20 to 30 percent of the rock and rarely show moderate deformation in the center of thick cooling units. Where alteration is least intense, delicate glass-shard textures are preserved, but all glass is altered to greenish smectite clavs, giving the rock a bluish-green color (e.g., at Cleator Bend). Heavier alteration obscures glass-shard textures and produces mosaics of smectite, zeolite, and quartz, giving outcrops a light-purple to cream color (e.g., on the south slope of Boulder Ridge). Unit Tbo reaches a maximum thickness of about 120 m in the Boulder Ridge area. A K-Ar age of 20.3 ± 0.2 Ma was obtained on plagioclase from Cleator Bend (Sutter, 1978), but unit Ts and related rocks dated at about 19.4 to 25.5 Ma overlie or cut unit Tbg; thus the 20.3-Ma K-Ar age is probably affected by alteration. Unit **Tbg** is partially correlative to the Cleator Bend member of Hammond and others (1980, 1982) but, as mapped by them, also includes part of their beds of Detroit and the Boulder Ridge member

terbedded ash flows (Tbla) (Oligocene?) - Includes all epiclastic and pyroclastic rock units in unit Tb that are stratigraphically below unit Tbu. Unit Tbl is composed dominantly of lithic-ricl tuffs with abundant lapilli- and coarse-ash-size lithic fragments in a fine ash matrix. Unit Tbl contains abundant volcaniclastic sandstone, mudstone, and debris flows. The amount of finegrained volcaniclastic rock in unit Tbl is much larger than in unit Tas, which is dominated by debris flows with abundant lapilli- to block-size clasts. Debris flows of unit Tbl are very similar to debris flows of unit Tss. A few analyses of lava clasts from unit Tbl have high Fe/Mg ratios and high total Fe, typical of tholeiitic lavas in unit Ts and clasts of unit Tss. Thin andesite and basaltic andesite lavas are interbedded locally. Nonwelded and a few welded ash flows occur sporadically throughout the section, becoming more abundant in the upper part where they are separately mapped as unit Tbla. All glass in units Tbl and Tbla is altered, giving glass-rich units a distinctive green to blue-green color. Alteration is intense enough in most outcrops to have affected the plagioclase to some degree, producing zeolites and clay along fractures. Unit Tbla is chiefly nonwelded to partially welded ash-flow tuff with a purplish to greenish color and 3 to 7 percent phenocrysts, chiefly partially altered plagioclase, in the matrix. Mafic silicates are mostly altered to green phyllosilicates, although minor clinopyroxene survives in some outcrops. The volume of unit Tbl is greater than the total volume of all the other units of the Breitenbush Tuff. A minimum thickness of about 2.2 km of unit Tbl is exposed in the map area. Unit Tbla reaches a maximum thickness of about 500 m west of East Humbug Creek. In view of the alteration that affects all of unit Tbl, all K-Ar ages are probably minimum ages. K-Ar ages of 23.2 to 24.3 Ma have been obtained on ash-flow interbeds (Sutter, 1978; Hammond and others, 1980, 1982). Units **Tbl** and **Tbla** are both older than unit **Ts**, which appears to overlie or intrude units Tbl and Tbla in the northern part of the map. Unit Tbla and Tbl are thus both older than 19.4 to 25.5 Ma, the age of unit Ts and related rocks. Unit Tls overlies unit Tbl west of the map area. Isotopic age data for unit TIs indicate an age equal to or greater than 26.46 ± 0.52 Ma (see discus-

sion of unit TIs, below). Hammond and others (1980, 1982) mapped unit TLiz primarily as the

CUB POINT BACHELOR MIN dex map showing tectonic and geographic features with mapping of other workers Scale 1:250,000 MAP SYMBOL Fault - ball and bar on downthrown side --------- Probable plunging anticline Strike and dip of beds Geologic mapping of others Walker and others, (1985) their Coopers Ridge andesite and as Nohorn andesite Tss erson Mountain others (1980, 1982) andesite/diorite or pyroxene andesite/diorite by Hammond and others (1980, 1982) and, in ash-flow sequences, possible intracaldera landslide deposits Basaltic vent complex of unit QTb (upper Pliocene to lower Pleistocene) QTv Basaltic vent complex of unit Tp (upper Miocene to lower Pliocene) Basaltic vent complex of unit Tmb (middle to upper Miocene) Dacitic and rhyodacitic vent complex of unit Tmd (middle to upper Miocene) Tby contact with unit Tla Tib

Basalt and basaltic andesite dikes, plugs, and sills (middle Miocene to Pliocene) Andesite dikes, plugs, and sills (upper Oligocene to Pliocene) Dacite and rhyodacite dikes, plugs, and sills (upper Oligocene to Pliocene) Tda

Cleator Bend member of the Breitenbush Formation. They mapped unit Tb) as the beds of Deothers (1980, 1982) troit, although other rocks, including andesitic lavas and plug domes of the Sarding Series of Thayer (1939) and unit **Tss** of this map, are also included in their beds of Detroit

